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The Micro Weather Station is intended to be a highly miniaturized, unattended, air-deployable and expendable package for the clandestine collection of meteorological and other environmental data in littoral land areas. (It is anticipated that the basic MWS design may be modified for marine use at a later date.) The operational version of the MWS will contain a suite of microsensors, a GPS receiver, a satellite communications transmitter, a digital processor with interface electronics, and a self-contained power supply with solar cells. It will be packaged to be as small and inconspicuous as possible, ruggedized to permit deployment by ejection from aircraft, and designed for low cost, large-scale production. It should have an operational lifetime of several months with data sampling and transmission performed once per half-hour.

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Covert Micro Weather Station for Littoral Areas

**Final Technical Report
CDRL Item A010**

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I. Introduction

This document is the final report for the Micro Weather Station R&D program carried out by Space Computer Corporation under Contract Number N00014-95-C-6005 issued by the Naval Research Laboratory, Stennis Space Center (NRL-SSC). This effort, which was initiated in December 1994, has been managed by the Center for Tactical Ocean Warfare Support (Code 7406) at NRL-SSC.

II. MWS General Description

The Micro Weather Station is intended to be a highly miniaturized, unattended, air-deployable and expendable package for the clandestine collection of meteorological and other environmental data in littoral land areas. (It is anticipated that the basic MWS design may be modified for marine use at a later date.) The operational version of the MWS will contain a suite of microsensors, a GPS receiver, a satellite communications transmitter, a digital processor with interface electronics, and a self-contained power supply with solar cells. It will be packaged to be as small and inconspicuous as possible, ruggedized to permit deployment by ejection from aircraft, and designed for low cost, large-scale production. It should have an operational lifetime of several months with data sampling and transmission performed once per half-hour.

Under Phase I of our R&D contract we developed an experimental version of the MWS utilizing conventional packaging, several commercially-available microsensors, an 8-bit microcontroller, and a battery power supply. This unit was demonstrated at NRL-SSC using the Argos UHF satellite communications system. The Argos system has been employed over the past fifteen years or so for low-volume data transmission from oceanographic buoys and research vessels as well as from animals and even in-flight birds. For operational MWS purposes, the Argos system is unfortunately not suitable because of its limited geographical coverage and non-real-time operation (an Argos satellite passes overhead only once or twice per day at best). However, it is the only existing satellite communications system able to operate with extremely low transmitter power (hundreds of milliwatts) with a simple low-gain transmitting antenna. (A higher-gain, directional antenna that required accurate pointing would not be practical for the low-cost MWS.) These unique features result from the fact that the system bandwidth is limited to a very low value, providing data transmission at a maximum rate on the order of 50 bits/second.

For Phase I demonstration purposes it was not feasible to develop a miniaturized version of the Argos transmitter to fit within the MWS package. A relatively large, commercially-available Argos transmitter was therefore employed, in a separate package, and the Argos satellite receiver available at NRL-SSS was used for data collection and display. The Argos transmitter was nearly three times the physical volume of the Phase I experimental MWS package.

During Phase II we added GPS and other capabilities to the experimental version of the MWS and miniaturized it to fit within the envelope of the ALE-47 chaff dispenser used by Air Force aircraft and now being adopted by the Navy. A photograph of the MWS developed in Phase II is shown in Figure 1. This effort involved the use of high-density packaging as well as the addition of a GPS receiver module, a rechargeable battery with solar cells, and a miniature

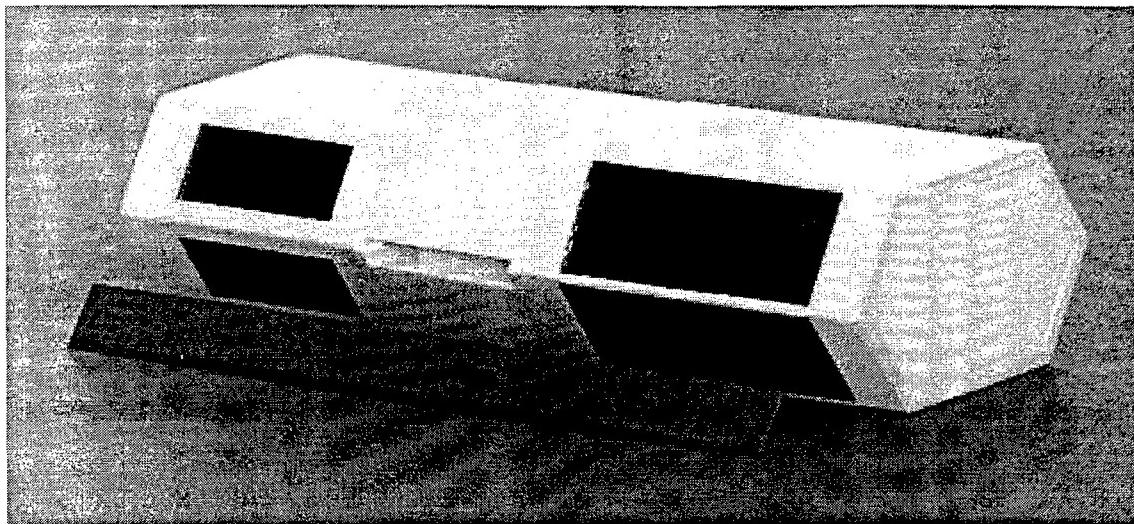


Figure 1. Photograph of Micro Weather Station developed in Phase II.

UHF transmitter capable of ranges up to a kilometer or so with an extremely small transmitting antenna located within the MWS package. In effect, this transmitter simulated the eventual microwave satellite transmitter we envision for the operational MWS. (It could also serve to deliver signals to a larger conventional satellite transmitter some distance away). The system electronics, as well as some analog electronics, had to be miniaturized onto a custom double-sided printed circuit board in order to fit within the small volume available in the MWS housing. In addition, new software programs were written for the microcontroller within the MWS to accommodate the function of the GPS receiver and the new terrestrial transmitter. Since the Argos receiving system could no longer be used for the Phase II demonstration, a new base station had to be created to receive signals from the transmitter, interpret them and display them. A laptop computer connected to a very small, battery-operated portable receiver was chosen for the base station. New software programs were written for the laptop to accept the data from the receiver and display the measurement and GPS data in a real-time fashion. One of the advantages of this configuration is that the system can be demonstrated at any time without the need for a satellite overhead. The demonstration of the Phase II MWS prototype was completed in early November, during which sensor data and GPS data were successfully received from the MWS by the base station in an off-site location.

Figure 2 shows a crosssection of the Phase II demonstration package including the microsensors, the system electronics board with micro-controller and interface electronics, the GPS receiver board and antenna, the rechargeable battery with solar cells, and the miniature UHF transmitter board with its antenna. This package is small enough for additional room to be available within the ALE-47 chaff dispenser envelope for a parachute, ejection devices, etc. The package is 6.5 inches long and 1.5 inches high, with a maximum width of 2.5 inches.

We anticipate that a low-bandwidth satellite communications system permitting the use of an ultra-low power, highly miniaturized up-link transmitter with a miniature omni-directional antenna will become available in the future for the operational version of the MWS. This system should operate in the microwave portion of the RF spectrum, should provide global coverage, and should operate in a near-real time fashion. We believe that such a system is feasible and that

it would be highly useful for a number of other important applications, both military and commercial. We understand that several contractors are investigating the development of a low-bandwidth system of this type.

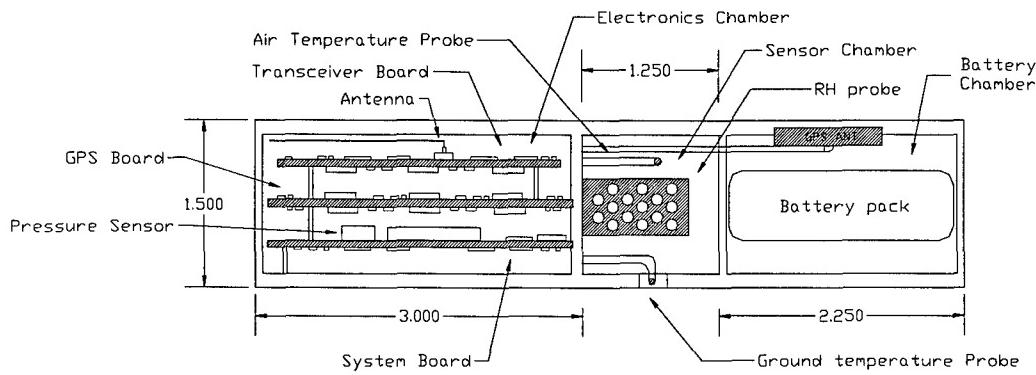


Figure 2. Crossection of MWS prototype used for Phase II demonstration.

In the eventual operational version of the MWS, the electronics circuitry and other components should be ruggedized to withstand the high g-forces associated with aircraft ejection and parachute landing. Room will be available for a microwave satellite transmitter and its antenna, which is assumed here to operate at L-band (1.6 GHz). The transmitter antenna can be similar to the miniature patch antenna used now for the GPS receiver (which also operates at L-band). The operational version will also be shaped as shown in Figure 1 so that it will tend to land on one of its two largest surfaces when it reaches the ground after ejection and parachute descent. In order for the MWS antennas, solar cells, etc. to be facing in the nominally upwards direction, the lower surface of the package is made identical to the upper one, with duplicate antennas, apertures, etc. It may also be possible in an operational version to include additional sensing capability beyond that of the Phase II prototype based on progress in micromachining and microelectronic technology. For example, currently available sensors for wind measurement and ceiling height are just not practical for miniaturized systems such as the MWS, but research in making these sensors smaller and less expensive is underway.

III. MWS Microsensors

The experimental version of the Micro Weather Station was miniaturized in Phase II to fit within the envelope of the ALE-47 chaff dispenser used by Air Force aircraft. The miniaturized version includes the same commercially-available sensors that were used in Phase I for atmospheric pressure, relative humidity, atmospheric temperature, and surface temperature. All of these microsensors are highly miniaturized, very low in cost and require very little power. The pressure sensor, for example, which utilizes a micromachined silicon structure is only 0.7" in length, including its protective package, costs about \$10, and averages only 0.5 milliwatts of power in operation.

These microsensors should be adequate for many operational applications of the Micro Weather Station. Other applications, however, may require additional microsensors for such parameters as wind speed and direction, visibility, cloud ceiling, etc. There are no microsensors available at the present time which meet the special MWS requirements of very small size, low power and low cost (although large, cumbersome versions of such sensors can be purchased from several commercial suppliers). It will therefore be necessary to undertake R&D efforts to improve existing technology and to develop suitable hardware.

It should be noted that a promising approach to wind measurement which does not require a mast to eliminate surface effects is the use of ground-based doppler lidar. A miniature unit of this type would be similar in principle to existing large units (which are about the size of an office desk), but would utilize many orders of magnitude less power (since the maximum altitude required would be only a few meters rather than tens of kilometers). It is possible that such a sensor could also be used to measure cloud ceiling, visibility, and (perhaps) precipitation. Currently available sensors for these parameters already employ lidar and other electro-optical technology, but much R&D work is required to reduce them to a practical size for the MWS.

The barometric pressure sensor employed in the MWS is a piezoresistive transducer that is made from micromachined silicon. The sensor uses a vacuum sealed behind a sensing diaphragm to provide a reliable pressure reference. The sensor outputs a high-level analog signal that is proportional to the applied pressure, and the signal from the sensor is fed directly to the analog-to-digital converter. The sensor also incorporates integrated thin-film temperature compensation as well as two stages of signal gain for the output signal. The nominal range of operation of the sensor is -40 °C to +125 °C over which the temperature compensation is applied. The expected accuracy of the sensor is +/- 5 mb over the range 0 to 50 °C, and slightly poorer at lower temperatures.

Relative humidity is measured by a low-cost, polymer capacitive GEI-Cap RH sensor. The sensing element consists of porous, thin gold electrodes that are deposited over a humidity sensing polymer designed for rapid diffusion of sensed water vapor. The porosity of the elements permits water to enter and leave easily and also allows for fast drying and rapid calibration. In addition, the properties of the film allow the sensor to survive complete immersion in water with no loss of accuracy. The sensor features a temperature coefficient of 0.05% RH/ °C and exhibits linearity better than +/-2%. Since the sensor is a simple capacitive element, a sensing circuit is needed for incorporation within the micro-weather station. The circuit specified by the vendor was found to be inaccurate over certain conditions so a new sensing circuit was designed with the aid of the vendor. To reduce volume in the MWS, this circuit was incorporated in the system board designed and fabricated by SCC. The output of this

circuit is tuned to produce a voltage between 0 and 5 volts for the full range of relative humidity and is fed to the A/D converter on the system board.

The two types of temperature measurement, air and surface, are made by precision thermistor circuits. The thermistor elements are manufactured from the oxides of several metals and are extremely small (about 0.1" diameter). Their small size is responsible for the very small time constant they exhibit in settling on a newly impressed temperature. In still air the time constant is a maximum of 10 seconds, and the time it takes the sensor to adjust to a new temperature is about 6 time constants or 60 seconds. The output of the sensor is highly nonlinear so the accuracy of the measured temperature is in part dictated by the order of the polynomial used to fit the plot formed by the calibration data. To achieve 0.2°C accuracy, the vendor recommends a third-order polynomial (a fourth-order was used to provide a somewhat better fit). Thermometric drift is also extremely low at 0.02°C/100 months for a nominal temperature of 25 °C or less.

In addition to the weather sensors, a simple high-impedance divider circuit was used to measure battery voltage, the output of which was fed to the A/D converter. By using matched components, temperature compensation was provided, and the output was found to be highly linear with voltage over a wide temperature range.

The calibration coefficients used to derive the weather sensor measurements from the A/D output are shown in Table 1 below. The coefficients were generated by Xplot which is an automatic curve-fitting program in which polynomial order is specified by the user. The pressure sensor was found to be extremely linear, and so only a first-order equation was required. A third-order polynomial was required to achieve a good fit for the relative humidity sensor data, and fourth-order polynomials were required for the two temperature sensors. The polynomials used are of the following form: $A + Bx + Cx^{**2} + Dx^{**3} + Ex^{**4}$

Table 1. Polynomial coefficients for sensor data.

Sensor	Meas. Unit	No. bits	A	B	C	D	E
Baro. Pressure	mb	12	102.87	0.2740			
Relative Humidity	%	12	4.9793	0.005406	9.5656e-6	-1.2729e-9	
Air Temp.	°C	12	69.048	-0.1158	7.9091e-5	-2.7684e-8	3.4315e-12
Surface Temp.	°C	12	70.531	-0.1259	9.1131e-5	-3.3015e-8	4.2010e-12
Battery Voltage	volts	8	0.0	0.03906			

IV. MWS GPS system

The system used to determine position in the MWS Phase II prototype is based on the commercially-available, miniaturized MicroTracker LP GPS receiver manufactured by Rockwell. The receiver is composed of an unpackaged printed circuit board, which incorporates all the analog and digital electronics required for decoding GPS signals, and a GPS patch antenna. To reduce the physical space it would require, the GPS patch antenna is used as a ceramic component without its weather-proof housing. The receiver board is housed in the electronics chamber of the MWS, the patch antenna is mounted in the sealed battery chamber, and a microcoaxial cable provides connection between them. The receiver board is the largest of the three boards in the electronics chamber, measuring 2.0" x 2.8" x 0.36", and is mounted in the center of the board stack, where there is adequate clearance. The board is rated for operation over a temperature range of -40 °C to +85 °C. A manufacturer's drawing of the board is shown below in Figure 3.

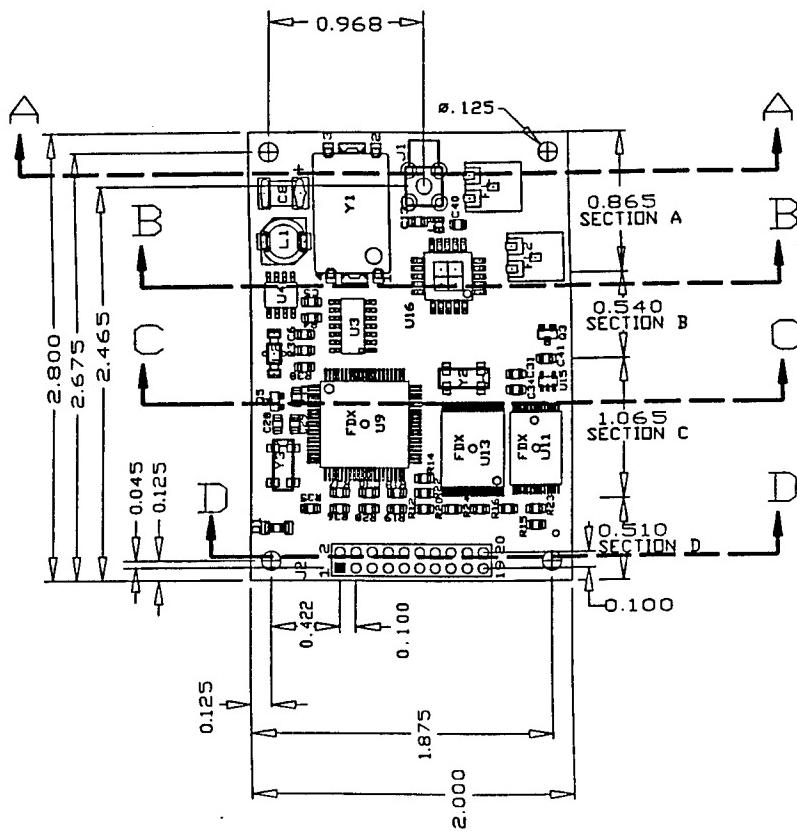


Figure 3. Rockwell GPS MicroTracker LP printed circuit board.

The MicroTracker system can operate with two basic message format protocols: NMEA mode and binary mode. NMEA mode refers to the National Marine Electronics Association specification NMEA-0183, version 2.00. This mode encodes the GPS data before transmission

into ASCII format with headers and delimiters. The binary mode is a Rockwell-standard protocol which encodes the messages into fixed-length message packets in which each data element occupies a fixed position and length. We chose the binary approach for the MWS system because it delivers highly compressed data packets. Given the limited bandwidth of any likely low-power communications system (e.g. Argos satellite systems with 32-byte messages), the number of bits wasted on overhead needed to be kept to a minimum. The binary approach provides between 2 and 3 times the data density of the NMEA approach due to the small amount of header information and highly-compressed, extended bit-level, representation of large numbers. Another reason for choosing binary over NMEA is that only binary mode provides error outputs based on estimation errors. These error outputs are useful in determining the validity of a particular GPS solution and are part of the message transmitted to the base station by the MWS. (While the error values reflect estimation errors, they are not computations of actual error but may be viewed as an indication of how well the navigation solution has converged.) The downside to using binary format mode is that the base station must be programmed to decode data in the more complex binary format as opposed to the simple ASCII format of NMEA. This, however, is easily accomplished at the base station (personal computer) where computing efficiency and compactness of code are not issues.

Using binary mode, a wide array of data is available from the MicroTracker board, however, as previously mentioned, the amount of data that can be transmitted with practical low-power systems is limited. To reduce the amount of data to two transmission packets, only data that was considered essential was included. The table below lists each data element chosen for transmission to the base station, the units in which it is specified, its data type, its corresponding length in bytes, and its data packet location.

Table 2. GPS data elements chosen for transmission to the base station.

Name	Units	Type	Length (bytes)	Location (packet no. - byte position)
GPS Header/checksum		Binary	4	1-2 and 2-2
UTC Time of day	seconds	EFP	6	1-6
UTC Day	days	I	2	1-12
UTC Month	months	I	2	1-14
UTC Year	year	I	2	1-16
Expected Horizontal position error	meters	I	2	1-18
Expected Vertical position error	meters	I	2	1-20
Position dilution of precision	0.01	I	2	1-22
Time dilution of precision	0.01	I	2	1-24
Latitude	radians	EFP	6	2-6
Longitude	radians	EFP	6	2-12
Altitude	meters	FP	4	2-18
Horizontal dilution of precision	0.01	I	2	2-22
Vertical dilution of precision	0.01	I	2	2-24

I = Integer, FP = Floating Point, EFP = Extended Floating Point

In addition to the data elements generated by the GPS system, each transmission packet contains an ID byte (used as a start byte), a stop byte, and two bytes which denote the most recent sensor measurement count. This last item helps coordinate the time measurements with the sensor readings and is useful for archival purposes.

V. MWS Communications

A. Basic Requirements for Operational System

We have assumed that the meteorological and environmental data collected by the operational version of the MWS must be transmitted to a remote station at a maximum rate of once per half-hour. The data to be transmitted in a given message may consist of sensor data, MWS identification code, time/date tag, longitude, latitude, altitude, and system health/status. For each measured variable of sensor data, the following information may also be transmitted: mean, standard deviation, maximum, and minimum. Sensor readings may also be collected over shorter intervals than a half-hour (e.g. 5 or 10 minute intervals) and stored for transmission at the half-hour interval. The bare minimum message length for sensor data, excluding GPS information, would be on the order of 30 bytes. Messages that include GPS information or those that include multiple readings of the sensors could be as long as two hundred bytes.

The data rate required for near-real time operation is quite low. If we allow, say, 30 seconds for each message transmission, the maximum data rate will be only 50 bits/sec. It is theoretically possible, of course, to transmit at a higher data rate for a shorter period of time with the same amount of energy expended. However, we have assumed for simplicity that the data rate would be this value of 50 bits per second, and that the message duration would be 30 seconds, with two messages per hour of elapsed time.

For operational purposes, it is highly desirable that the MWS transmit data directly to a satellite, without the need for any form of ground relay station. This will greatly simplify the deployment operations and will reduce system cost. Since we wish to minimize the probability of MWS detection by observation of its transmitted signals, we should minimize the maximum MWS radiated power and, ideally, utilize some form of spread spectrum modulation--which will improve performance as well as make the transmitted signals harder to detect. The modulation technique employed can easily permit the simultaneous operation of, say, 1000 MWS transmitters on the same communications channel.

Other important requirements for the communications system are very small transmitter size and weight, including the antenna as well as the transmitter equipment. In fact, the antenna should be small enough to fit within the MWS package. It should also be essentially non-directional, to avoid the cost and complexity of an antenna pointing system. These features are most easily provided by a satellite uplink system which operates in the microwave region rather than in the VHF or UHF regions (which require a substantially larger antenna structure).

B. Potential Satellite Systems

1. Argos. The Argos UHF data communications system requires only 1 W of radiated power (even less for some specialized applications), is relatively inexpensive, and has been in operation for many years. Because the system comprises only two satellites (in low-earth, polar orbits),

however, a transponder is within view of the transmitter for only a brief period of time during every orbit (at best). Thus multiple, redundant transmissions are usually required to insure reception by the satellite for arbitrary user locations and transmission times. This requirement wastes a great deal of battery energy. Furthermore, a long period of time (many hours or even more) may elapse between transmission to the satellite and downlink reception of the data at a remote ground receiving station. In addition, there are many blind spots at geographical locations where the system cannot be used at all. Finally, the Argos transmitter requires a whip antenna about a foot long (or the equivalent), since it utilizes UHF frequencies. Such an antenna of course cannot be mounted within the MWS package and would be very awkward to deploy in a reliable, automated manner.

2. Orbcomm. The new Orbcomm satellite communications system now coming into service will use 28 micro-satellites in low earth orbits. The system is intended to provide two-way data and message communications on essentially a global basis. The data rate is 4,800 bits/sec, and the ground (user) transmitter radiated power is 5 watts. The system is intended for data and e-mail communications only, not for voice (which would require a considerably higher bandwidth).

The operation of the Orbcomm multiple access scheme is based on a satellite/user handshake procedure that requires the presence of a satellite downlink before the user is allowed to transmit. Thus the user must employ a satellite receiver as well as a transmitter, i.e., a transceiver. Orbcomm user transceivers have been developed by several manufacturers in the U.S., Israel and Japan. A typical transceiver occupies about 25 cubic inches (including room for battery), which is unfortunately too large for the MWS application. It also uses a relatively large, omni-directional VHF whip antenna (over one foot long). A key problem for the MWS application is the transmitter power, which is necessitated by the very small size of the satellite receiving antennas. These antennas are essentially omni-directional because the satellites are themselves very small (the complete satellite weighs only 87 pounds).

It may be possible to reduce the size of the Orbcomm user transceiver somewhat, but the relatively large power requirement and the need for a large VHF transmitting antenna make its employment for the MWS application less than ideal.

3. Other Possibilities. Although several low-bandwidth, data-only satellite communications systems have been proposed, none that would be well-suited for the MWS application appear to be under development. Essentially all of the future satellite systems thus far proposed will have sufficient bandwidth for voice operation, or even much higher bandwidth (for internet access and other applications).

We believe, however, that it would be possible to develop an MWS transmitter which would operate at an extremely low power (well under one watt) and which would utilize **existing** (geosynchronous) satellites. The system would exploit the low data rate of 50 bits/sec to minimize the uplink power required, and would operate at microwave frequencies in the C-band region (6.4 GHz) to be compatible with existing satellite transponders and to minimize antenna size. The antenna could consist of a small patch antenna about the size of a GPS receiving antenna (1 inch square) mounted entirely within the MWS housing.

The possibility of such a system was investigated by us with the assistance of personnel at the Jet Propulsion Laboratory. A detailed link budget analysis was computed for the following conditions:

- Spread spectrum modulation (36 MHz system bandwidth)
- Transmitting antenna gain 7 dBi
- Receiving system gain 27 dBi (typical of commercial geosynchronous satellites)
- System G/T: 0.38 dB/K

With a transmitter output power of only 500 mW, the computed link margin is 18 dB, which is considerably larger than necessary for reliable transmission. Because of budget and other limitations on our contract, we were unable to proceed further with this investigation. However, we understand that several firms are currently investigating this possibility for other applications.

C. Demonstration Transmitter

Since none of the available direct-to-satellite transmitters were small enough for inclusion in the basic MWS housing, a terrestrial transmitter was chosen for the MWS Phase II prototype. The unit is an Adcon Micro-T short-haul transceiver that operates at a frequency of 916 MHz. The unit transmits data in a pass-through mode with 29-byte long packets and a selectable data rate from 1200 to 9600 baud. Since the vendor recommends lower rates for higher transmission reliability, the data rate was chosen to be 1200 baud. The unit transmits directly to a similar transceiver unit that is connected via a communications link to an IBM-compatible PC, with a line-of-sight range up to one-half mile. The transceiver hardware was incorporated into the MWS design as an unpackaged printed circuit board that measures 0.99" x 2.60" x 0.42", as shown in Figure 4. The board is mounted in the electronics chamber within the housing directly above the GPS board. Since the operating frequency is high and the distance short, a small 3.5" long antenna was feasible. This antenna was mounted directly below the top surface of the housing in the electronics chamber.

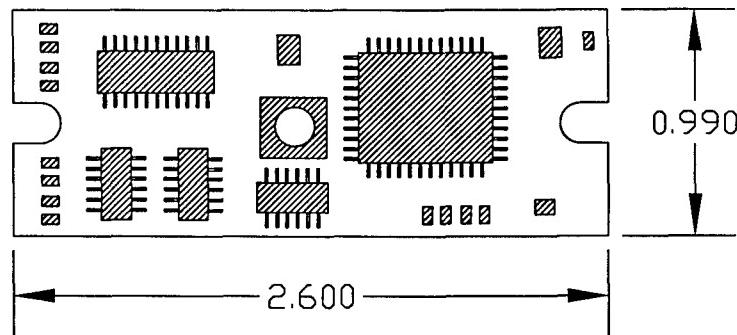


Figure 4. Adcon Micro-T transceiver printed circuit board.

VI. MWS System Electronics

The Phase II MWS employs highly miniaturized electronic components to control sensor measurements, initiate GPS position acquisitions, transmit sensor and GPS data, as well as coordinate all MWS functions. The electronic circuits used for the system electronics were designed by Space Computer Corporation and were incorporated into a custom printed circuit board also designed by SCC. At the heart of the system electronics is the microcontroller and its supporting electronic components. The microcontroller selected is an Atmel 89C52 which is basically an enhanced CMOS model within the Intel 8051 family of 8-bit microcontrollers. This particular version was chosen due to its very low power consumption and ease of programming. The clock crystal for the microcontroller was selected to be of low frequency (3.86MHz) so that machine cycle time would be fairly slow at 3 microseconds. This helps cut down power consumption during periods of relative inactivity (timer mode), which represent the bulk of the time the device is powered up, but does not harm the overall performance of the system. The power consumption of the microcontroller in the timer mode is only 0.5 mw. The microcontroller is directly connected to latch circuitry and an SRAM device which provide it with low-power external memory. When not being used, the SRAM and latch devices together draw only 20 microamps which allows them to be continuously powered up along with the microcontroller.

The analog-to-digital converter chosen is a low-power CMOS, 12-bit multichannel design that allows up to 11 single inputs. Five single inputs are used in this MWS design and include air temperature, surface temperature, barometric pressure, relative humidity, and battery voltage. The A/D converter is a switched-capacitor, successive approximation device whose output is connected to one of the input ports of the microcontroller. The total unadjusted error, which comprises linearity, zero-scale and full-scale errors, is +/- 1.75 LSB, while the maximum conversion time is 10 microseconds. The device is controlled by commands from the microcontroller which determines which measurement is to be made and retrieves the data in bit form from the device. The A/D converter is usually in a quiescent state in which it draws only 25 microamps, allowing it to be powered on continuously with the microcontroller.

The power supply is broken into three independent sections, two of which may be shut down on command by the microcontroller. The first power supply is controlled by a voltage regulator that remains on continuously; this feeds power to the microcontroller and its supporting circuitry. A second voltage regulator powers all the sensor circuits and is shut down between measurements. A third voltage regulator powers the GPS board which is shut down immediately after a valid reading or after a timeout, as determined by the microcontroller. The power consumption of the switchable voltage regulators is only 30 microwatts in the off-state, which is much less than the consumption of the microcontroller itself in the quiescent condition. When they are turned on, the voltage regulators operate with a very high power efficiency of better than 90%. Solar cells are also incorporated on the outside of the MWS housing and help recharge the batteries to a limited degree. Due to their necessarily small size, they can extend battery life significantly only when the demands on the MWS are low.

Obviously, the types of operations performed by the MWS and the frequency of those operations dramatically impact the energy it consumes, which in turn affects its expected operational life. For example, the GPS board draws as much as 170 ma when powered up, and the sensors together require as much as 30 ma when activated. In contrast, the microcontroller

and supporting components draw only a fraction of a milliamp in quiescent mode. The ratio of power consumption between active GPS use and quiescent mode operation for the MWS can be as great as 1000. Therefore, to prolong MWS life the interval between sensor measurements and the interval between GPS measurements should be made as large as possible while still fulfilling mission requirements. A discussion of how power is conserved through the use of software routines is given in the section on MWS software.

In order to fit the system electronics within the electronics chamber of the MWS, a custom printed circuit board was designed to interconnect all MWS electronic components other than the GPS function and transmitter function. Since the GPS board must occupy the middle position within the electronics chamber (the widest portion), the width of the system board could not be any greater than 1.8 inches. To fit within this constraint, the design required component mounting on both sides as well as the use of small outline surface mount packages for all components. In addition, the minimum design rules for interconnecting the components were reduced to 6 mil wide traces and 6 mil wide spaces. The finished assembled board measures 1.60 x 2.80 x 0.42 inches. A fabrication drawing of the system board showing component placement on the top surface and board dimensions is given in Figure 5. The top surface has the microcontroller (large square component in the center) and related components, while the other side (not shown) has the relative humidity sensor circuitry as well as other analog circuitry. Separate ground structures and trace isolation were used to shield the analog circuits from the digital circuits to reduce crosstalk noise that might affect sensor readings.

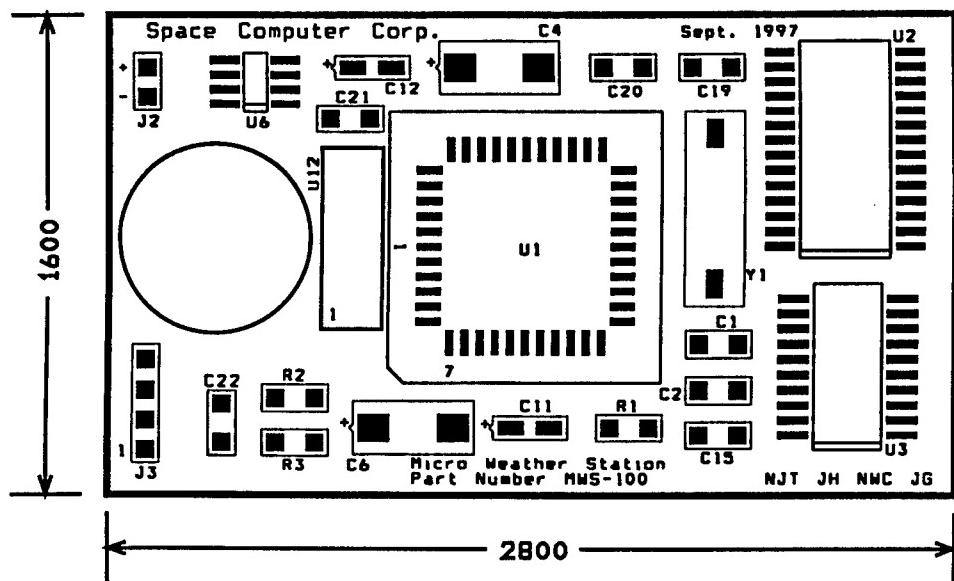


Figure 5. Custom dual-sided board designed for system electronics.

VII. MWS Prototype Demonstration

The operation of the MWS prototype developed in Phase II was demonstrated on 7 November 1997 to a representative of the Naval Research Laboratory. The demonstration was conducted at the offices of Space Computer Corporation. The demonstration consisted of a brief overview of the functionality and construction of the micro weather station followed by a real-time field use of the MWS prototype.

The demonstration employed the following components:

MWS prototype loaded with assembler program *Demo55*

Base station transceiver (Adcon Micro-T) with portable battery pack and comlink cable

Laptop computer (90 MHz Pentium-based) loaded with C program *ReadMWS_V5*

The equipment required to demonstrate MWS operation, as shown in Figure 6, was set up in less than 2 minutes. First, the small base station transceiver and its battery pack were attached mechanically to the back of the laptop computer. Next, the base station transceiver was connected via comlink cable to the comm port on the back of the laptop computer and the base station was powered up. Next, the Windows 95 operating system and the micro weather station monitoring program *ReadMWS_V5* were brought up on the laptop computer. The MWS prototype was then placed in a nearby open field and activated.

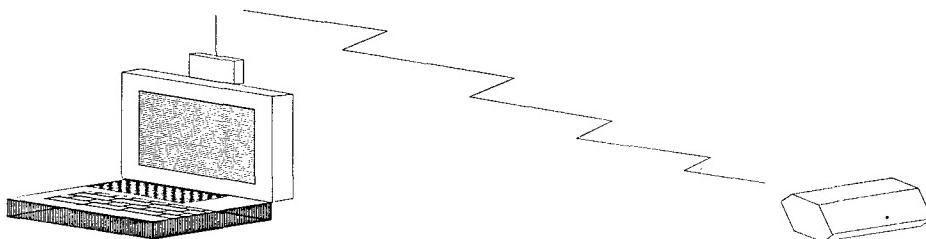


Figure 6. Equipment for MWS demonstration.

The MWS initialized itself upon powerup and started to transmit sensor measurements from all of its sensors as required by the *Demo55* software. Four successive sets of valid sensor readings were received by the monitoring program (one set per minute), indicating that the MWS, base station and laptop computer were all functioning properly. After four sensor reads, the program shifted into GPS position mode. In this phase, the MWS receives positional data from GPS satellites, and if satellite coverage is sufficient, forms a position solution. If a position solution is not formed within 15 minutes, the MWS program assumes poor coverage and resumes satellite acquisition 24 hours later. This timeout is designed to maximize battery life since the GPS mode consumes enormous quantities of energy compared to other MWS operations.

During the demonstration, a valid position solution was not formed within the 15 minute limit and the program reverted back to sensor measurements. While in the GPS mode, the MWS was

able to receive the valid time, which was used by the monitoring program to timestamp subsequent sensor readings. The timestamp for each set of sensor measurements was displayed on the screen after the GPS mode was finished and sensor measurements resumed. Limited time on the day of demonstration prevented another powerup of the MWS for receiving GPS data.

VIII. MWS and Base Station Software

A. Micro Weather Station Software

The Micro Weather Station relies on the 89C52 low-power microcontroller to control all MWS operations. The microcontroller program *Demo55*, an 8-bit application, was developed by Space Computer Corporation to operate the MWS in a real-time demonstration. The source code is written in Intel 8051 assembly language and was compiled using the Intel ASM51 assembler. The resulting hex file was loaded into the program memory of the 89C52 using a Philips MP-51 PLD programmer.

The program is activated automatically upon powerup of the MWS. The activation is accomplished by an RC circuit on the RESET input to the microcontroller. Since the MWS was intended to be autonomous in hostile locations, the MWS is not designed to be shut off remotely once deployed. The only method of shut-down is physical intervention with the MWS unit. The unit may be programmed, however, to have a specified time of operation after which the system shuts down. The present program, *Demo55*, runs the MWS continuously until the power supply is exhausted.

The operation of the MWS is basically split into two modes: sensor measurement and GPS position determination. Transmission of the resulting data occurs immediately after measurement or during position acquisition at predetermined time intervals. Upon MWS powerup, the program initiates the first set of sensor measurements. The microcontroller turns on power to the sensors, waits for the sensors to settle and commands the A/D converter to sample the outputs of the sensor circuits. After readings are taken, the microcontroller shuts down the sensors, compresses and formats the readings for transmission, and stores the readings in external memory. The transmitter is then activated and three sets of measurements are taken from the external memory and sent to the transmitter for transmission to the base station. The three sets consist of the most recent set, the next most recent set (one interval ago) and the set from three intervals ago. After the first four sets of measurements are made, the program switches the microcontroller into GPS mode.

In GPS mode, the microcontroller activates the GPS receiver and initiates GPS position determination. The GPS board delivers various messages to the microcontroller as it receives satellite data and works toward a position determination. The microcontroller determines which messages are being received and which ones to decode. When position data and error data are received, the program takes the data and makes a determination as to the validity of the position solution. The validity is based on the received expected error data which is used to determine solution convergence. When the solution validity criteria are satisfied, the program terminates the GPS mode and does not return to GPS mode. While the GPS board is generating solutions, the microcontroller sends a solution every minute to the transmitter for transmission to the base station. When no solutions are valid (as determined by the program), the program will continue to operate in GPS mode for 15 minutes before timing out. If a timeout occurs, the GPS is

reactivated in 24 hours (the GPS will be reactivated every 24 hours until a valid solution is determined). This relatively long period is to insure that battery drain is kept to a minimum. Immediately after a GPS solution has been found, or after the GPS has timed out (no valid solution), the program resumes sensor measurement and sensor data transmission.

To maximize the amount of information sent within the fixed packet size required by the transceiver technology, the program provides compression of data before transmission. To maximize the quantity of sensor data transmitted, the bytes are packed so that no byte is empty or even half-empty. For example, sensor measurements which are typically 12-bits are concatenated without regard to byte boundaries (2 data fragments may occupy the same byte). In this way, it becomes possible to send 3 sets of sensor measurement data within a single packet of 29 bytes. For the GPS measurement data, the program sends the data in binary form as created by the MicroTracker GPS board. This form is much more compact than an ASCII representation, since each data element is represented from 16 to 48 bits with 5 to 14 significant digits, respectively.

An important feature of the program is its use of timeouts and shut-downs of parts of the MWS circuitry to minimize power consumption while not in use. In particular, the program controls the powerup and shutdown of the sensor circuits and the global positioning system (GPS). The terrestrial transmitter consumes very little power when not transmitting and does not need to be powered down separately. The normal on-time for the sensor circuits before measurement is 20 seconds, while the normal interval between sensor measurements for most applications is 10 minutes up to 1 hour. Both the sensor on-time and the measurement interval are selectable variables within the program. The sensor on/off time ratio typically ranges between 1/30 to 1/180. For demonstration purposes, the measurement interval was chosen to be short (1 minute). To conserve power the GPS is activated at most once per day and in most land-based situations only as often as required to achieve one valid solution. The program will shut down the GPS after achieving a solution that is deemed to be sufficiently accurate or when a 15 minute limit is reached. The GPS may not be able to determine position if poor satellite coverage exists (15 minutes without a valid solution is usually an indication of poor satellite coverage). The program may reactivate the GPS on a time interval that is selectable (default is 24 hours), or only as many times as is necessary to achieve a valid solution (also selectable). The GPS on/off time ratio is typically 1/96 or smaller.

B. Base Station Software

The program *ReadMWS_V5* was developed at Space Computer Corporation to receive, decode, display, and record Micro Weather Station data using an IBM-compatible personal computer. *ReadMWS_V5* a 32-bit application designed to be run from a Windows95 MS-DOS window. The source code is written in the C language and was compiled using the Microsoft Visual C++ compiler.

During operation of the MWS, sensor data and GPS data are transmitted by the Adcon transceiver onboard the MWS to the Adcon base station, which is connected to the COM1 serial port of a personal computer. Data are transmitted in packets of 29 bytes at a rate of 1200 baud. continually examines the input buffer of the COM1 port, looking for any new bytes of data which have been received. The data are read and decoded. A given data packet contains either sensor information or GPS information. Sensor information is transformed by means of polynomials derived from the calibration curves of the various sensor devices on the MWS, to

obtain meaningful numbers for temperature, barometric pressure, etc. The GPS data are decoded to produce time, date, latitude, longitude, and altitude information.

The decoded data are displayed on the PC's screen and are also written to an ASCII file. Each time a new data packet is received, the screen is updated and the new data are appended to the file. Two display formats are available for viewing. Figure 7 shows the primary display, which is the default display that comes up when the program is activated. This display includes the most recent basic GPS information (latitude, longitude, date, and time) and three sets of sensor data (the most recent set of readings, the set immediately preceding it, and the third most recent set). Note that the time at which each set of measurements was taken is also displayed. By pressing the spacebar on the PC keyboard, the user can toggle to an alternative display, shown in Figure 8, which gives the most recent complete set of GPS data, including expected errors and dilutions.

GPS POSITION

UTC Time of Reading: 1:16:34	PST Time of Reading: 17:16:34
UTC Date of Reading: 10/30/1997	
Latitude: N 34 deg, 1 min, 44.55 sec	
Longitude: W 118 deg, 27 min, 56.49 sec	
Altitude: 79 meters	

SENSOR MEASUREMENTS	Most Recent (N)	Previous (N-1)	3 Ago (N-3)
Time of Measurement (PST):	17:18:33	17:17:34	17:15:33
Barometric Pressure (mb):	1023.8	1022.4	1024.1
Ground Temperature (deg C):	19.5	19.6	19.6
Air Temperature (deg C):	18.3	18.4	18.4
Relative Humidity (%):	45	45	44
Battery Voltage (V):	10.0	10.0	10.0
Measurement Count:	5	4	2

Figure 7. Primary display showing sensor readings and basic GPS position data.

GPS POSITION

UTC Time of Reading: 1:16:34	PST Time of Reading: 17:16:34
UTC Date of Reading: 10/30/1997	
Latitude: N 34 deg, 1 min, 44.55 sec	
Longitude: W 118 deg, 27 min, 56.49 sec	
Altitude: 79 meters	

GPS POSITION ERROR DATA

Expected Horizontal Position Error: 6 meters
 Expected Vertical Position Error: 5 meters
 Geometric Dilution of Precision: 748.29
 Position Dilution of Precision: 622
 Time Dilution of Precision: 416
 Horizontal Dilution of Precision: 403
 Vertical Dilution of Precision: 474

Figure 8. Alternative display showing complete set of most recent GPS data.

IX. Summary and Conclusions

A Micro Weather Station station was successfully designed and built to gather and transmit sensor and GPS data in a form factor that makes it possible for usage in air drop applications. The prototype MWS constructed was used to measure weather parameters, determine position from data received from GPS satellites, and transmit the data in appropriate format to a portable ground station. The MWS functions were compressed into a package measuring 1.5" x 2.5" x 6.5" through the use of miniaturized electronics and custom circuitry. A demonstration of the MWS prototype was held at Space Computer Corporation in which the MWS performed all functions as designed.

The one major issue that needs to be resolved before an operational version of the MWS can be deployed is the availability of an appropriate satellite network and a corresponding miniaturized transmitter. The existing Argos satellite network, used by the Navy for the past 15 years for its drifting buoy programs, has too many limitations in both coverage and bandwidth to be practical for operational MWS use. Several alternative satellite configurations have recently been deployed by commercial vendors, and the Navy is currently considering several of these systems for use on board ships and ground stations. The type of satellite transmitter used within an operational version of the MWS will necessarily depend on that decision. It is clear, however, that with recent progress in microelectronics technology, a miniaturized transmitter for most of these satellite networks could be built within the space constraints of the MWS.

To ruggedize the MWS for use in an operational system, additional work must be performed. In particular, the housing of the MWS must be developed to withstand the shock of explosive launch from an airplane. Some of the boards must also undergo redesign to use low-mass components to withstand the high g forces associated with such use. It may also be desirable to expand the capabilities of the MWS for operational use by developing additional sensors. In particular, sensors that measure wind and ceiling height, which today are large and cumbersome, may in the future be small enough to be incorporated in the MWS envelope. Other sensors that are still in the research stage but which someday could be incorporated in the MWS are seismic detectors, micro-cameras, and spectrum analyzers.